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ABSTRACT

Small wind systems that provide from 0.5 kW to 2.0 kW of power are often used to pump water for domestic uses and livestock. Thousands upon thousands of mechanical water pumping systems have been installed over the years to meet the water requirements of people and livestock. However, poor reliability because of high maintenance and aging equipment are causing many water users to seek other energy sources to power their pumps. The United States Department of Agriculture-Agricultural Research Service has developed an independent wind-electric water pumping system for irrigation and large water users, and recently, conducted tests on small sized systems for livestock or domestic water pumping.

A wind-electric water pumping system consists of a wind turbine that produces AC electric power at variable-voltage, variable-frequency; a pump controller; and a standard utility-grade electric motor and pump. Each system was operated at several pumping heads and the performance evaluated for at least 700 hours of operation at each head. Measurements made were wind speed, water-flow rate, water-discharge pressure and electrical frequency, voltage, and current. One minute averages of data sampled at 1 Hz were recorded and used in an analysis by the method of bins.

The wind speed at which water pumping was initiated was dependent on the pumping head. A wind speed of 3.0 - 3.5 m/s was required to initiate flow for pumping heads of 17 - 45 m. A delay in flow initiation was noted for heads above 50 m. In all cases, the wind turbine reached its maximum pumping rate at a wind speed of 14 m/s when the wind turbine began to furl and the rotor slowed reducing the voltage and frequency. Average daily water pumping rates were 19,930 L/day for a pumping head of 17 m and were reduced to 12,534 L/day when the pumping head was 45 m. This daily volume of water was 45% higher than the volume of water pumped by a wind-mechanical water pump.

INTRODUCTION

Traditionally man has supplied water for his domesticated livestock by using springs, flowing streams, and handdug

wells. One of the early uses of wind power was to pump water from shallow wells using bucket pumps [Fraenkel, (1)]. In the late 1800's, the American multibladed windmill was developed to pump water from deep wells. These systems provided a year-around water supply and allowed settlement of the area known as the Great Plains. With the deployment of electrical utility systems into rural America, many of these mechanical windmills have disappeared. The technology of the mechanical windmill has been exported to many countries, but because of inadequate maintenance, many of these systems are no longer usable.

An adequate year-round water supply is still a major stumbling block to livestock grazing in many arid regions. Ranchers have found that if sufficient watering places are not provided, livestock do not move to areas of the pasture where grass may be abundant. Cattle will graze about one kilometer from a water supply; therefore, several water supplies are needed in most large pastures. Many ranchers continue to haul water for livestock in remote areas.

Livestock animals require various amounts of water depending on their size and weight. Chickens and turkeys require the least amount of water with cattle and horses requiring the most. Table 1 contains a range of water use data for various livestock with smaller amounts applying to smaller animals or cool weather use and the larger amount applying to larger animals or hot weather use. The amount listed for dairy cattle includes the water

TABLE 1 Daily water requirements for various livestock [Neubauer and Walker (2)].

Animal	Liters/Day
Beef Cattle	40 - 50
Dairy Cattle	60 - 75
Sheep & Goats	8 - 10
Swine	10 - 20
Horses	40 - 50
Chickens (100)	8 - 15
Turkeys (100)	15 - 25
Evaporation	800 - 1200

used for cleaning the milking barn. For most remote locations, water storage for 3 to 5 days is usually provided. If water is stored in an open tank, then the amount of water lost to evaporation must be considered in determining the volume of water needed to meet the demands of the livestock.

Over half of the population of rural areas of the world do not have a safe and dependable water supply. Many of these people depend on surface waters that are polluted and harmful to their health. Water can not be pumped because often times energy and labor for servicing engine-driven pumps is unavailable. The availability and cost for new electrical grid service are often prohibitive. New developments with electrical generating wind machines have provided a new potential for pumping water in remote areas with wind energy. A new wind-electric water pumping system for remote areas has been developed by the United States Department of Agriculture, Agricultural Research Service, Bushland, TX, USA. The performance of a wind-electric pumping system will be presented and the performance compared to a mechanical wind pump.

DESCRIPTION OF SYSTEMS TESTED

The wind-electric water pumping system used in these tests consisted of electric generators that were direct-drive, permanent-magnet alternators with a 3-phase, 240 V, AC nominal output. The alternators produced a frequency and voltage that was proportional to the rotational speed of the rotor. Each system had the ability to run unloaded and had a mechanical rotor overspeed control. The unit furled and slowed the rotor by turning sideways out of the wind flow. The 3.05-m diameter, three-bladed rotor unit was manufactured by Bergey Windpower¹. The rotor blades were constructed of pultruded fiber reinforced plastic and operated at rotor speeds between 100 and 500 rpm. The hub height of the unit was 20 m.

The wind pumping system was controlled by an electronic circuit that sensed the frequency output of the wind turbine generator and when the preset cut-in frequency was reached, a standard motor solenoid connected the electric power from the wind turbine to the standard electric pump motor. The wind turbine was rated at 1500 W and was connected to a 1100 W electric motor and powering a 740 W pump.

The pump used in this study was a multistaged submersible pump powered by a three-phase, 240 V standard submersible electric pump motor. Pump and

motor operated at 3450 rpm when powered at a constant 60 Hz. The system was operated at several pumping heads to determine the effect of pumping head on the wind speed at which pumping was initiated and to measure the pumping rate at various wind speeds under the different pumping heads.

Data for these tests were collected by sampling the hub-height wind speed, water-flow rate, water-discharge pressure and water depth (total pumping head), electrical frequency, electrical voltage, and electrical current at a rate of one sample per second and averaging these data for one minute. The one-minute averages were recorded on micro-dataloggers and transferred from data modules to PC's for processing and analysis. Data were sorted by the method of bins using wind speed. The bin-width was 0.5 m/s. Wind speed bins between 2 and 13 m/s usually had over 1000 samples (minutes of data). Average values and standard deviations were calculated for each bin (0.5 m/s wind speed). Standard deviations were typically less than 10% of the average values.

RESULTS

The premiss for the wind-electric water pumping system is to allow the wind turbine to operate at variable speed; thus producing a variable-frequency, variable-voltage system that can supply electric power directly to a standard electric motor. The permanent-magnet alternators would nominally produce 3-phase, 240 V AC power at 60 Hz. The 1500 W generator system produced a frequency between 0 and 70 Hz. The corresponding voltage was between 0 and 270 V as shown in Figure 1. The controller was set to connect the pump motor at a cut-in frequency of 35 Hz. The voltage rise was delayed because of the voltage drop at start-up of the motor. At a wind speed of 6.0 m/s, the system was stabilized and the voltage and frequency ramped-up together until the

FREQUENCY and VOLTAGE Bergey 1500

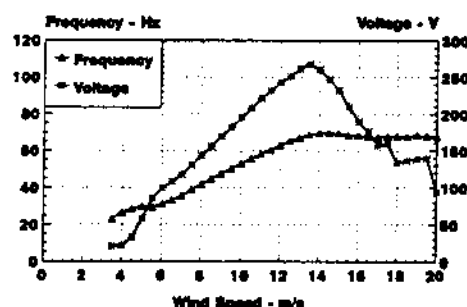


Figure 1 Measured frequency and voltage from a 1500 W wind turbine for each wind speed bin for a pumping depth of 45 m.

¹ The mention of manufacturer's names is made for information only and does not imply an endorsement, recommendation, or exclusion by USDA-Agricultural Research Service.

VOLTAGE/FREQUENCY RATIO

Bergey 1500

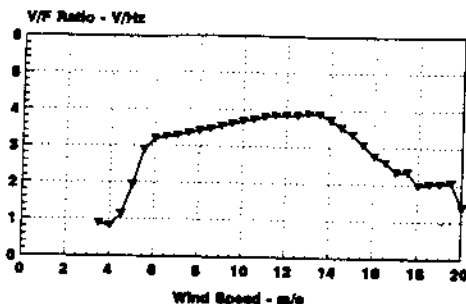


Figure 2 The voltage/frequency ratio for a 1500 W wind turbine while pumping from a depth of 45 m.

rotor furling at a wind speed of 13.5 m/s. The benefit of this type of system is clearly shown in Figure 2 where the voltage-frequency ratio (V/F ratio) is shown. The V/F ratio exceeds 3 at 6.0 m/s wind speed and remains almost constant until furling at 13.5 m/s wind speed. The electric motor, rated at 240 V and 60 Hz, will operate best at a voltage to frequency ratio near 4.0. Although, the V/F ratio varied from 3 to 4, this was in the acceptable range for most motors. When the V/F ratio is constant, the current draw to the motor is proportional to the power provided to the motor and is always equal or below the design current; thus not causing motor overheating.

To determine the wind speed at which pumping begins, data were sorted by flow during the one-minute period. When the flow was 0.0, the data were assigned to an "off" bin and when flow was 0.1 or above, data were assigned to an "on" bin. Figure 3 shows the ratio of the number of "on" samples as compared to the total number

RATIO OF ON-TIME TO TOTAL TIME

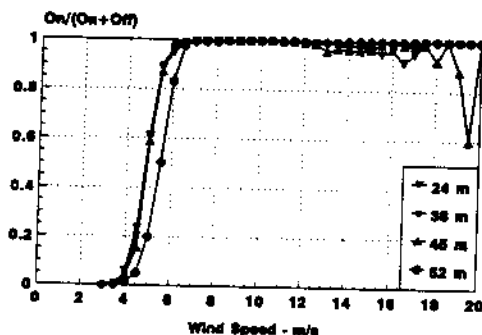


Figure 3 Ratio of "On" samples to "On + Off" samples for four pumping lifts where 0 represents Off and 1 represents On.

of samples (on + off). These data show that the pump started between 3.0 and 3.5 m/s and the pump ran almost all the time when the wind speed was above 6 m/s. For this pump, a delay in pumping was noted when the pumping lift was greater than 50 m.

The pumping rates for four pumping heads are given in Figure 4. Three additional pumping heads were tested, but were removed from the chart for clarity. For the 17-m pumping head, flow was initiated at a wind speed of 3.0 m/s and a peak flow of 40 Lpm was recorded at a wind speed of 12 m/s when furling occurred. The peak flows varied from 36 to 41 Lpm for all heads tested. The flow curves for heads of 17 m and 45 m were selected for conducting a prediction of yearly pumping.

Monthly wind speed histograms from 10 years of wind speed data collected at a height of 10 m at Bushland, TX were used to calculate an average daily pumping volume for each month. The results of this analysis are shown

PUMPING RATES @ VARIOUS HEADS

Bergey 1500

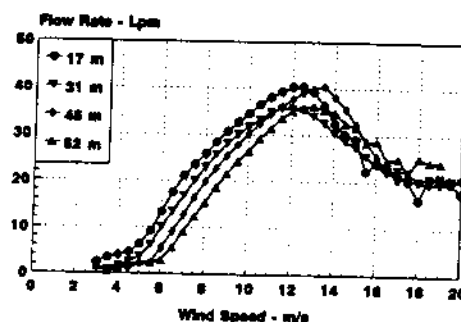


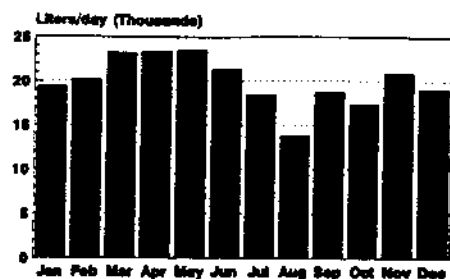
Figure 4 Water flow rates for four pumping depths using a submersible pump and a 1500 W wind turbine.

for the two pumping heads in Figures 5 and 6. Figure 5 shows the average daily water pumped for each month when the pumping head was 17 m. The largest amount of water was provided in the month of May, but little difference was found between May and March or April. The rate was 23,490 L/day for May and it dropped to 13,860 L/day for August, the lowest daily amount pumped. The average daily amount pumped was calculated at 19,930 L/day; enough for about 200 head of beef cattle.

Figure 6 shows the daily average water pumped when the pumping head was 45 m. The highest daily average water pumped was in March with a volume of 16,139 L/day and the lowest was in August with a daily volume of 7,349 L/day. The average for the year was 12,534 L/day and all months, except August, exceeded 10,000 L/day. A beef cow requires 40 to 50 L/day; therefore, this pumping system would provide for well over 100

Daily Water Pumped @ 17 m Lift

1500 W - Avg 19,933 L/day



Wind speed 1983-1991

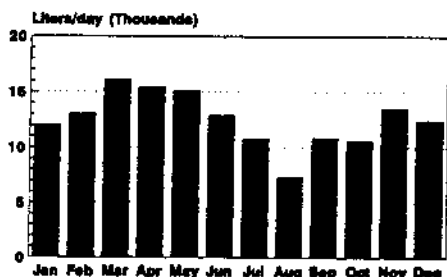
Figure 5 Average daily water volume pumped for each month calculated using 10-yr wind speed histograms from Bushland, TX. The pumping lift was 17 m.

head. I suggest that a rancher plan to have a storage tank that would hold a five day supply and that the herd be sized for the lowest daily amount available. However in this case; a rancher might choose to select the average of July, August, and September or 9,680 L/day as his available water supply.

Since the multi-bladed windmill has been used for many years to provide livestock water, its performance was compared to this electrical water pumping system. A month by month comparison of the two pumping systems using the average daily water volume is given in Figure 7. The average daily water volume for the wind-electric system exceeds the wind-mechanical system by almost 4,000 L/day or 45% more water. The wind-electric pump provided more water in all months except August when the average wind speed is significantly lower than the other months. These data clearly show that electrical

Daily Water Pumped @ 45 m Lift

1500 W - Avg 12,534 L/day

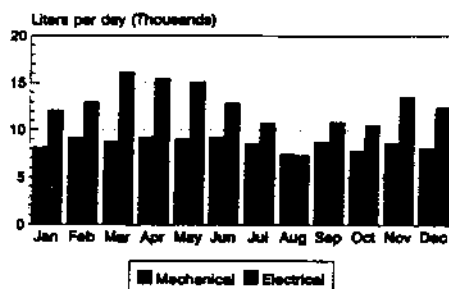


Wind speed 1983-1992

Figure 6 Average daily water volume pumped for each month calculated using 10-yr wind speed histograms from Bushland, TX. The pumping lift was 45 m.

Daily Water Pumped @ 45 m

Mechanical (8,600 L/day) and Electrical (12,534 L/day)



Wind data from 1983 - 1992

Figure 7 Comparison of the average daily water pumped between a mechanical windmill and a wind-electric water pumping system. The pumping lift was 45 m.

wind pumps operate better than mechanical systems when the average wind speed is above 5 m/s and operated about the same as mechanical systems when the wind speed is between 4 and 5 m/s. [For more information on performance of mechanical wind pumps, see Molla and Clark, (3)]. Comparisons made between mechanical and electrical wind pumps for pumping heads of 17 m to 30 m show that the electrical wind pump will pump about twice as much water as the mechanical wind pump.

Considering other comparisons between the two systems, I find that the electric wind turbine rotor at 3.05 m is slightly larger than the mechanical windmill rotor at 2.44 m. The mechanical windmill starts pumping at a lower wind speed than the electric system, but the difference is less than 1 m/s and is dependent upon the pumping head. Probably the most important comparison is shown in Table 2 where the cost of the two systems is compared. The turbines and towers cost about the same, but the controls and pumps costs are much different. The higher cost of steel pipe and the requirement for a pump rod for the mechanical system more than offset the cost of the pump controller for the electrical system. These small-sized submersible pumps are often supported by a hanger wire and polyethylene pipe is used to transport the water to the surface; thus reducing the cost of the pump installation. The overall system cost are almost identical for the two systems.

CONCLUSIONS

A 1500 W wind-electric water pumping system that operates independent of the electric utility was operated at 7 different pumping heads ranging from 17 to 59 m. Performance data were collected for over 700 hours at each pumping head. During all these tests, the wind turbine, pump controller, electric submersible motor and

TABLE 2 Catalog list prices of various components used in a wind-powered water pumping system. Pumping depth is 50 m.

Component	Mechanical	Electrical
Wind Turbine	\$3275	\$3195
Tower	1800	1576
Pump Control	—	935
Pump	194	381
Motor	—	283
Pipe & Rods	1050	300
Total Cost	\$6319	\$6670

pump required no maintenance. These systems experienced wind speeds in excess of 30 m/s. I feel that these machines are reliable and robust enough to be installed in remote areas where the greatest need for livestock and domestic pumping occur. When the pumping head was 45 m, average daily water volumes averaged 12,530 L/day with highest daily rates occurring in March and the lowest in August. Water volumes exceeded 10,000 L/day in all months except August. Average daily water volumes increased to 19,930 L/day when the pumping head was 17 m using the same sized submersible pump.

This wind-electric water pumping system has consistently performed better than the wind-mechanical water pumping system. Although data are presented for one pump and four pumping heads, several pumps using three

different wind turbines have been tested, and all perform better than mechanical pumps. Much of the improved performance of wind-electric systems is a result of using submersible pumps that have a low starting torque and flow is proportional to the speed of the pump. This is in contrast to the piston pump used with wind-mechanical water pumping systems which has a high starting torque and the flow is proportional to the stroke length and stroke speed. Mechanical systems furl and reduce the pump speed when the wind speed exceeds 10 m/s, thus wasting significant amounts of energy when the wind speed exceeds 10 m/s. Since most electrical wind turbines have a hub height of 20 to 30 m, then the pumping performances predicted for the wind-electric system would be better because wind speeds are usually higher at 20 m than 10 m.

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3. Molla, S., Clark, R. N., 1994, Proc of Windpower'94, AWEA, 261-268.



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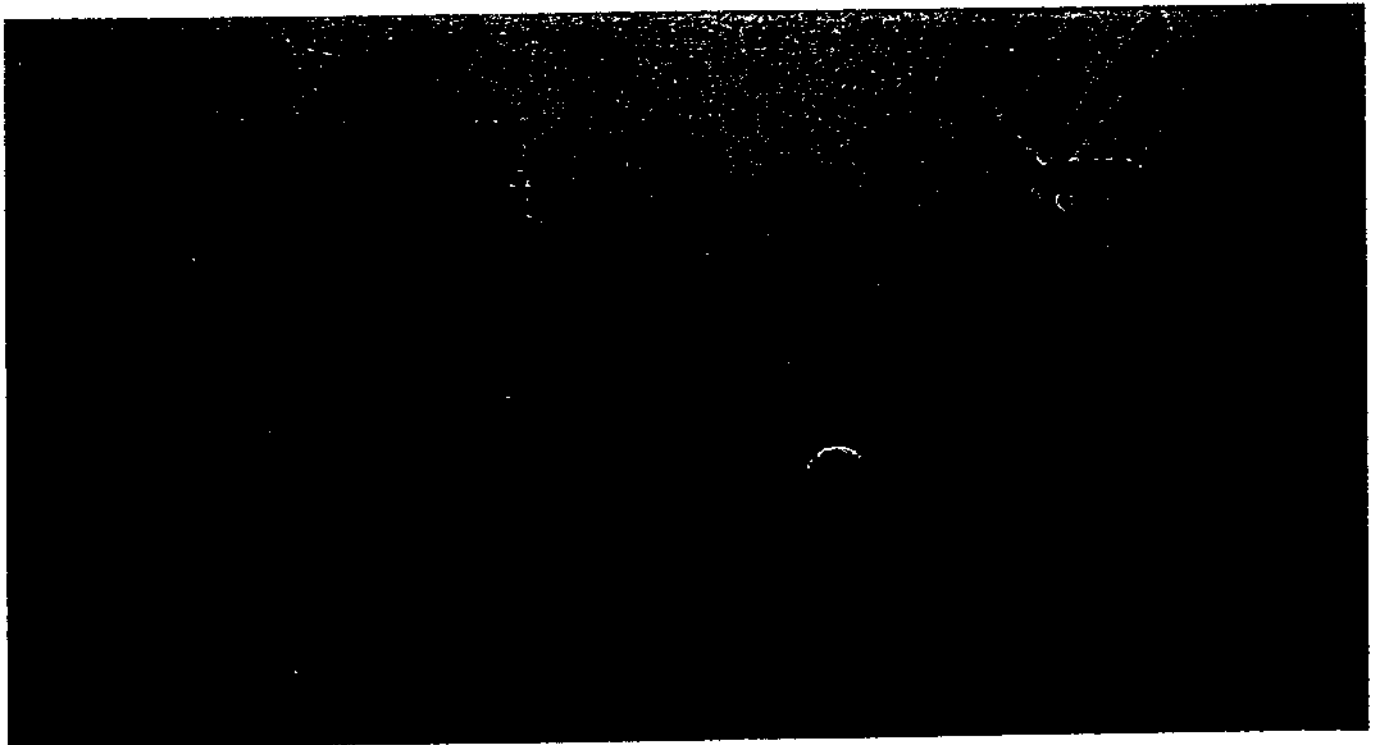
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